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Introduction.

The investigation of the microflora of peat began towards the end of the last century in Germany and Denmark, and was later taken up in the U.S.A. and in England. Attention was directed mainly to the physiology of the micro-organisms present, but information was also obtained on their relative abundance and distribution in different types of peat. It was shown conclusively that fungi, actinomycetes and bacteria occurred at all depths in fen peat, *Niederungsmoor*, (Ritter, 1912 ; Waksman, 1929). The acid peats of blanket and raised bog, *Hochmoor*, which have been investigated were found to possess an abundant surface microflora of bacteria and fungi, but reports differ as to the distribution of the micro-organisms in the lower layers. The earlier German workers (Ritter, 1912) found the lower layers below 50 cm. to be sterile. Waksman (1929), on the other hand, reported that, although fungi and actinomycetes were absent in the lower layers of these bogs, bacteria were found to increase in numbers with increase in depth. Waksman and Purvis (1932), investigating the microflora of two American *Hochmoor* profiles, found as before that bacteria increased with depth ; the number of fungi decreased with depth, and were found to be absent below 75 cm.

Little work has been done on the identification or ecology of the microfungi occurring in peat. Dale (1914) isolated 20 species of fungi from a 10 g. sample of mountain peat taken at 600 feet above Loch Lomond, and 18 species from a like sample of reclaimed fenland. She recorded their morphological and systematic characteristics only, and gave no indication of their relative abundance or ecology. Four of the species isolated by her from mountain peat were isolated in the present investigation. Jensen (1931) investigated the fungal flora of a large number of Danish soils, among them a number of peats. He found *Trichoderma* in all soils except marsh ; *Mucor ramannianus* was common in heath and moor, and *M. spin-*

osus (?) was present in two of the four moor peats investigated. Penicillia were common in moor and heath, but were often overshadowed by *Mucor* species. Aspergilli were sporadic. In the soils and peats investigated, the ratio $\frac{\text{fungi}}{\text{bacteria} + \text{actinomycetes}}$ was found to increase with decrease in pH, and the correlation was close.

Bisby, James and Timonin (1933) and Timonin (1935) were the first to investigate the variation of the fungal flora with depth. They included one peat profile in their study of the virgin podsols of Canada. This profile was from a wooded fen, pH 5 (ca.), moisture content 83% at the surface, and depth 1·5–2 m. The numbers of fungi, bacteria, and actinomycetes decreased with depth. Penicillia formed 60% of the fungi isolated, and these were usually species that did not occur in other soils. Three species of *Penicillium* that occurred in the lowest layer of the peat were not found in any of the other soils studied.

Boswell and Sheldon (1951) investigated the microbiology of the upper 5 cm. of the *Eriophorum vaginatum* peat of the Pennines. They found that *Cephalosporium* spp. were the dominant fungi in every sample, and that *Pullularia pullulans* and *Cladosporium herbarum* were also present in every sample. Six other genera of fungi, including *Penicillium* were occasionally recorded.

In the present study, the micro-fungi occurring in two peat profiles of the Dublin–Wicklow mountains and their ecological relations have been investigated, special attention being paid to variation with depth. One of these peats clothed a steep slope and was covered by a remarkably pure *Callunetum* ; the other was a typical *Scirpus* blanket bog of the Wicklow Mountains. Although the investigation was necessarily limited as regards both scope and time, some tentative idea was obtained of the ecological structure of the microfungal flora of upland peat. It is hoped that the many questions left unanswered and even uninvestigated will be followed up at a later date.

Peats Investigated.

Peat A, Callunetum. The surface vegetation on this peat was :—

Calluna vulgaris	d. (5) knee-deep.	*Vaccinium myrtillus*	r. (1⁻)
Deschampsia flexuosa	o. (2⁻)	*Hypnum cupressiforme*	d. (5⁻)
Ulex gallii	r. (1)	(in ground layer)	

[Figures refer to " Total Estimate " of Braun-Blanquet.]

This peat, about 70 cm. deep and rather spongy, covers the steep, south-facing slope of Tibradden Mountain, and extends between 1,200 and 1,400 feet, o.d. Drainage from the slope is by seepage through the peat, and at one point only is a waterlogged flush formed. The profile consisted of two distinct layers. The upper layer (1) was light brown and spongy in texture, the lower layer (2) was dark brown or black and permeated by the fine roots of *Calluna*. The lower few inches of the peat were mixed with granite detritus, and may be considered to form a third layer (3). Three

sampling sites, which will be referred to as A_1, A_2, and A_3, were chosen from slightly different levels, A_2 being the highest, 30 yards from the transition to a wet bog covering the upper slopes. A_1 was 100 feet lower down the slope, and A_3 100 feet lower still. The depths of the profile layers for each site are given in Table 1.

Table 1. *Depth of layers in the A peat.*

Layer	A_1	A_2	A_3
1	0 –38 cm.	0 –33 cm.	0 –28 cm.
2	38–75 ,,	33–65 ,,	28–55 ,,
3	75–88 ,,	65–70 ,,	55–63 ,,

Peat B, Scirpus Bog. Two sites, B_1 and B_2, were chosen on the *Scirpus* blanket bog typical of extensive areas on the higher slopes of the Wicklow Mountains. They lay about one mile S.E. of Glendhu Mountain, near the Dublin–Wicklow county boundary at 1,700 feet, o.d. B_1 was situated on the Wicklow side of the county boundary where a gentle slope towards the S.E. was flattening out, and it bore the following vegetation (angiosperms) :—

Trichophorum caespitosum (*Scirpus caespitosus*)	f. (3^+)	*Eriophorum vaginatum*	o. (2^-)
Calluna vulgaris	f. (3)	*E. angustifolium*	f. (3)
Erica tetralix	f. (3)	*Narthecium ossifragum*	o. (2)

The peat was 205 cm. deep, and was remarkably uniform throughout. One metre of peat was cleared from the face-bank of a fresh turf cutting, and the samples from below 20 cm. were taken from this peat which was not yet affected by the drainage. Samples from the upper 20 cm. were taken from undisturbed bog, 20 yards away from the cutting.

B_2, from the Dublin side of the county boundary, was perhaps a more typical *Scirpus* bog with *Trichophorum* (*Scirpus*) *caespitosum* more definitely dominant (4), and *Calluna* less frequent and more stunted (2). The terrain was level and undisturbed by turf cuttings. The peat was uniform and similar to that of B_1 in the levels examined (0–60 cm.).

Method of Sampling.

Warcup's (1950, 1951) soil-plate method of sampling and isolation was used. Samples of peat were obtained by digging a hole, cleaning one face, and taking plugs of the peat in sterile glass specimen tubes from the following levels :— 0 (surface), 2·5, 5, 7·5, 10, 15, 20, (25), 30 cm., and every 10 cm. to the bottom. A small portion (0·005 g.–0·010 g.) was transferred from the centre of this plug to a sterile petri dish. About 0·5 c.c. of sterile water was added, the dish rotated to disperse the humus particles, and then 8–10 c.c. of cooled agar medium was poured into the plate, which was again rotated to disperse the particles evenly. The medium used for the original soil-plates was that suggested by Warcup, namely Czapek-Dox agar + 0·5%

yeast extract (G.Y.E.), acidified to pH 4 by the addition of 1/20 phosphoric acid. Three (or two) plates were inoculated from each sample, and were incubated at 22·5° C. Colonies which developed on these plates were isolated as soon as possible by transferring them to malt or Czapek plates. After 10 to 15 days it was usually possible to count the number of colonies of the vigorous species appearing on the original soil plates. The plates were kept at least a month in order to record the slow-growing fungi.

Bacterial soil plates were prepared from the B_2 profile in the same way, using nutrient broth agar as medium. A series of plates was also prepared from the A_2 profile, but in this case the peat was streaked on the solidified medium with a sterile needle. Only one bacterial plate was prepared per sample.

Fungi Isolated.

Microscopic examination of the raw peat revealed very little fungus mycelium or spores. On placing the peat in water, a suspension of small particles, less than 0·5 mm. diameter, was easily formed, so that the peat was not penetrated by a matrix of mycelium as, for instance, Waksman, Tenney and Steevens (1928) reported for forest soils. Microscopic examination of the plates, one or two days after planting when growth was beginning, showed that the colonies originated from the interior of humus particles. It was therefore impossible to tell whether the colonies originated from spores or mycelium. Only in one case, (B_1 20 cm.), were colonies seen to originate from spores, in this case thick-walled chlamydospores.

Although many of the species of fungi occurring in the peats investigated undoubtedly remain unrecorded, 61 species were isolated in pure culture. A relatively large number of these species could not be identified, and have been given an identification number. 49 species were isolated from the A peat, 23 from the B peat, 11 species being common to both. Of these 11 species, 7 were Penicillia.

LIST OF SPECIES.

Species marked * have been recorded from one level of one site only. Those marked simply A, B, or AB have been recorded from many levels of the A, B, or from both peats respectively.

PHYCOMYCETES.

* *Mortierella pusilla* Oudemans (A_2 7·5).
M. sp.—M 1 (A).
M. sp.—M 9 (A).
M. sp.—M 2 (A)
* *Mucor hiemalis* Wehmer (A_2, 0).
M. Ramannianus A. Moeller (AB).
* *M.* sp.—M 5 (A_1, 10).
* *M.* sp.—M 6 (A_2, 2·5).
M. sp.—M 16 (B).

ASCOMYCETES.

Thielavia sp. Zopf.—M 21 (AB).
M 8 (A).

FUNGI IMPERFECTI.

* *Pyrenochaeta* sp. deNot.—M 15 (A_3, 0).
* M 26 (A_2, 63).
* *Aspergillus ustus* (Bain.) Thom & Church. (B_1, 15).
A. versicolor (Vuill.) Tiraboschi (AB).
* *Oospora variabilis* (Lindner) Lindau. (?) (A_2, 65).
Penicillium frequentans Westl. (AB).
P. implicatum Biourge. (A_2, 25).
P. lividum Westl. (AB).
P. spinulosum Thom. (AB).
P. thomii Maire. (AB).
* *P. variabile* Sopp. (A_2, 25).
P. canescens Sopp. (AB).
* *P. janthinellum* Biourge. (B_1, 7·5).
* *P. jenseni* Zaleski. (A_3, 50).
P. melinii Thom. (AB).
P. nigricans (Bain.) Thom. (B).
P. digitatum Sacc. (A).
P. oxalicum Curr & Thom. (A).
P. paxilli Bain. (AB).
P. roqueforti Thom. (B).
P. stoloniferum Thom. (A).
* *Scopulariopsis brevicaulis* (Sacc.) Bain. (Thom's Group I) (B_1, 7·5).
* *Hormodendron* (*? olivaceum*) (Corda) Bonarden. (B_2, 10).
Torula sp.—M 12 (A).
* *T.* sp.—M 47 (A_3, 7·5).
* *T. convoluta* Harz. (B_2, 2·5).
Trichoderma viride Pers. ex Fr. (AB).
Verticillium sp. Nees.—M 14 (A).
* M 45 (A_3, 0).
M 10 (A).

In addition, at least 20 distinct types were isolated that failed to produce any fructification.

Some of the unidentified species were very common, notably M 8, M 10, M 18 and M 19, the latter two from the sterile group. Since they were so common, it was thought advisable to add the following descriptive notes.

M 8. Colony fast-growing and spreading widely on malt agar, covering plate with loose, white mycelium in 2-3 days at 22·5° C. Perithecia isolated, appearing after 2-3 days; projecting above mycelium; when ripe (7 days) jet-black; wall

soft ; 400–500μ diameter, 700–900μ long, including long neck (400μ). Asci linear oblong (260μ × 20μ), bearing 8 linearly arranged black ovoid ascospores, which have slightly roughened wall, 23μ × 14μ. Ascus wall not staining blue with iodine ; thin, even at tip which is perforated by a pore. No paraphyses nor periphyses in ripe ascus. Spores embedded in mucillage extruded from ostiole when pressure applied.

M 10. Mycelium dark, septate. Colonies slow-growing, restricted ; forming a flat colony 15 cm. in diameter in 14 days on malt agar at 22·5° C. Colour variable in different isolates, grey, dirty yellow, slaty blue, or black. Appearing slimy on the surface in the early stages, but later becoming velvety due to production of coremia. Coremia abundant after 14 days, 750μ long, 20–30μ across at base, gradually tapering to a hyaline point. Conidiophores short, 15–20μ long, bearing up to 10 almost sessile conidia (stalks 1–2μ), unbranched or branched once or twice ; borne abundantly along coremia and also on prostrate hyphae. Conidia dark brown, spherical, thick-walled, smooth, 4μ in diameter.

M. 18. Mycelium dark, septate, forming a heaped colony, 4 cm. in diameter, 2 cm. high, in 10 days at room temperature on malt agar. Colony blue-green in colour. Sterile, but basal mycelium in medium septating with age to form thick-walled chlamydospores.

M. 19. Mycelium septate dark. Colony restricted, slow-growing, not larger than 2 cm. diameter on malt agar at 22·5° C. Basal hyphae dark brown, forming an overgrowth of whitish hyphae 5 mm. high. Chlamydospores formed in submerged hyphae on ageing.

Notes on Some of the Commoner Fungi.

PHYCOMYCETES. No Oomycetes were recorded, although Warcup (1951), using a similar method of isolation, isolated three species of *Pythium* from English grassland soils. *Mortierella* (4 spp.) and *Mucor* (5 spp.) were the only Phycomycetes isolated. *Mucor ramannianus* which constantly appeared in the surface layers of A and was also recorded as deep as 20 cm., was reported by Jensen (1931) from Danish heath and moor soils. Warcup (1951) records it from the B and the lower part of the A horizons of podsol grassland.

ASCOMYCETES. An unidentified species of *Thielavia* (M 21) occurred sporadically in A_2 and B_2. A Pyrenomycete, M 8, which defied all attempts at classification beyond the Hypocreales of Millar (1949) was the only species isolated which was strictly and consistently confined to a single layer. It was found in the 2·5 and 5 cm. samples of all three sites of the A peat. It was a very vigorous grower, and usually swamped other species on the soil plates except *Trichoderma*.

FUNGI IMPERFECTI. The majority of the genera and species isolated were of this type. *Penicillium* was by far the most abundant genus. Its species were identified according to Raper and Thom (1949).

Two distinct strains of *Penicillium lividum* were isolated. On Czapek agar, one strain produced colourless droplets of exudate, in reverse was saffron or tan to yellow, with the surrounding agar slightly green. There was no odour. The other strain produced no exudate, had a greenish-yellow reverse, a more velvety surface, and a very noticeable odour suggestive either of mushrooms or of rotting fruit. This species was isolated by Dale (1914) from upland blanket bog and from reclaimed bog.

P. melinii also showed two distinct strains, one characteristic of the A, the other of the B peat. The isolates from A may even represent several distinct strains. Some produced a golden-yellow exudate; some had a white margin of growing hyphae; the agar surrounding the colony was sometimes rose-coloured, sometimes yellow. Despite these differences, the colony appearance of the different strains isolated from A was basically similar. This strain also occurred in the B peat, but was uncommon. The other strain had a very distinctive creamy-rose opaque reverse, and was not mentioned by Raper and Thom (1949). It was found exclusively in the B_2 peat.

P. paxilli was found in A_2 at 0 and 5 cm. in the form described by Bainier with long conidiophores 1 mm. or more long. Another form, characteristic of the B peat, was close to Raper and Thom's typical species, but showed a marked tendency towards the characteristics of *P. citrinum*.

P. thomii was sporadically recorded from every sampling site except B_2, especially from the surface layers, though it occurred also at the bottom of A_2. It produced abundant pink sclerotia, but though kept in culture for long periods it failed to show any sign of ascus formation. It was rather variable in cultural characteristics, and sectoring was noted at times. *P. thomii* has been reported from peat and soils rich in humus by many authors:— by Bisby, James and Timonin (1933) from forest soils (common), by Dale (1914) from peat, by Bisby *et al.* (1935) as common in the surface layers of peat, rare in the basal layers.

P. spinulosum, reported by Raper and Thom to be, along with *P. frequentans*, the most common monoverticillate species typical of soil, was recorded from every site. Most of the cultures produced hard, gritty sclerotia, about 1·5 mm. in diameter, fawn in colour, and tending to be submerged in the agar. The production of sclerotia by this species was not reported by Raper and Thom, but, except for this character, the species isolated agreed in every detail with their description. The cultures isolated from the 5 cm. sample of B_1 and the 2·5 cm. sample of B_2 did not produce sclerotia.

P. roqueforti appeared only in B_2 at 5, 10, and 40 cm., appearing on one plate of each. Much work has been done on the physiology of this species. It has been found to flourish in an atmosphere of 5% oxygen and under quite acid conditions, and yet produce abundant proteolytic and lipolytic enzymes. Thus it seems to be perfectly adapted to live in a medium such as peat, and the record at 40 cm. seems to be genuine.

P. nigricans, isolated constantly from the upper layers of B_2, is very active in the decomposition of plant remains. Gilman and Werkmann (1936) found that it reduces the organic matter in corn-stalks by 16·9% in 21 days, as compared with 17·7% for *Trichoderma*. This species, along with *Trichoderma*, is therefore probably the most active decomposer in the upper layers of *Scirpus* peat, and the powerful antibiotics produced by both species probably retard the activities of other fungi.

The Aspergilli, as noted by other workers on the soil fungi of temperate regions, were of sporadic occurrence. *A. versicolor* isolated from A_2 (20 cm.) and B_2 (10 cm.) was recorded by Dale (1914) from Scottish peat, by Bisby, James, and Timonin (1933) from Canadian podsol, and by Warcup (1951) from the deeper layers of all the grasslands he investigated. *A. ustus*, from B_1 (15 cm.) was also recorded by Bisby, James, and Timonin (1933), and by Warcup (1951).

Trichoderma viride was common at the surface of all the sites sampled, and its frequency fell off with depth. This is shown in Figs. 1 g and 2 d which strongly

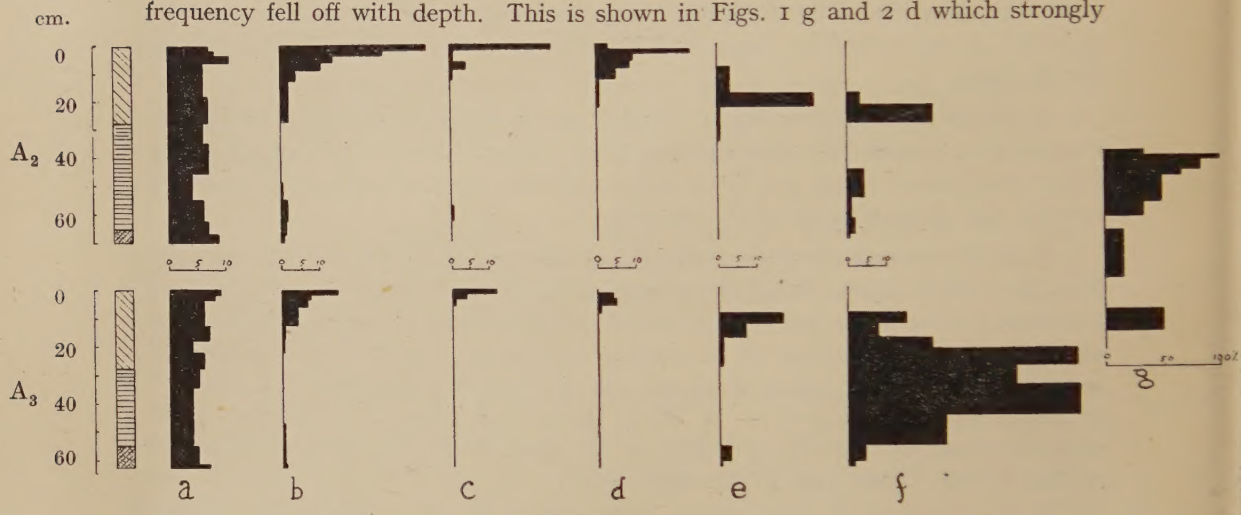


FIGURE 1.

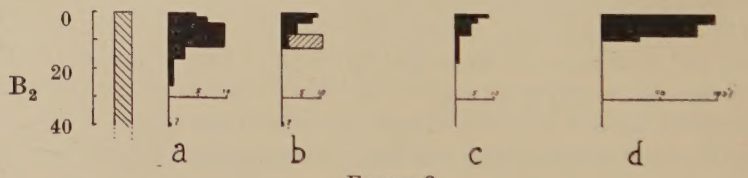


FIGURE 2.

FIGS. 1 & 2.—1. Distribution of Fungi in A_2 and A_3. (*a*) Total number of species recorded per sample. b.-f. Average number of colonies per plate of all *Penicillium* spp. (*b*), *Penicillium lividum* (*c*). *P. melinii* (*d*), *Verticillium* s.p. M. 14 (*e*) and of M 10 (*f*). g. Percentage of plates infected with *Trichoderma* (A_2 and A_3).

2. Distribution of Fungi in B_2. (*a*) Total no. of species recorded per sample. (*b*) Average no. of colonies per plate of all *Penicillium* spp. (shaded area represents a cluster of colonies on one plate, obviously arising from a mass of spores.) (*c*) Average no. of colonies per plate of *Mucor* sp. M 16. (*d*) Percentage of plates infected with *Trichoderma* (B_1 and B_2).

resemble Warcup's (1951) figure for the distribution of *Trichoderma* in grasslands with highly acid surface. This species has been reported by most authors who investigated the fungi of acid soil or of peat, and might be considered universal in these habitats. Since *Trichoderma* hyphae covered the whole plate before sporing, it was not possible to count the number of colonies per plate ; the diagrams are therefore computed on the % of plates infected.

Table 2. Distribution of the more common fungi in the different profiles.

*(Levels are given in cm. *0–5 means present in all samples between 0 and 5 cm. Bracketed figures indicate doubtful records).*

Species	A_1	A_2	A_3	B_1	B_2
Mucor ramannianus ...	0	0, 5, 10	0–5*, 20	—	—
Mortierella sp. M 1. ...	?	0, 5, 30	0, 2.5, 10, 15	—	—
M. sp. M 2 ...	?	0, 2.5, 7.5, 15, 30, 40, 65, 70	0, 20, 25	—	—
M. sp. M 9 ...	?	—	0, 2.5	—	—
Penicillium lividum ...	0–5, (40)	0–10, (60)	0, 5, (20)	0, 5, (125)	10
P. thomii ...	0, 2.5	0, 5, 7.5, 20, 60	0	2.5	—
P. melinii	7.5, 10	0–10, 20, (65)	2.5–7.5	—	0–10
P. spinulosum ...	0, 7.5, 10, 40	5, 25, 70	5, 63	2.5, 5, (60)	2.5, 25, 40
P. nigricans ...	—	—	—	—	0–5
P. paxilli	—	0,5	—	—	0–10
M 10	25–80	25, 50–70	10–63	—	—
M 8	2.5, 5	2.5, 5	2.5, 5	—	—
Verticillium sp. M 14 ...	25, 30, 60–80	5, 10–30, 50–65	10–25, 60, 63	—	—
Trichoderma viride ...	0–40, 75, 80	0–20, 60	2.5–7.5, 30, 40, 60	0–7.5	0–5
Thielavia sp. M 21 ...	—	5, 70	—	—	5, 15
M 18	—	—	—	5–20	5–15, 25
M 19	25–80	20–70	15, 25, 40	7.5	—
M 17	—	—	—	7.5, 20	2.5–10
Mucor sp. M 16 ...	—	—	—	—	0–20

VARIATION OF THE FUNGUS FLORA WITH DEPTH.

The plates prepared from the surface samples (0 cm.) of both peats were covered by a large number of colonies up to 1 cm. in diameter two days after inoculating. The colonies were too numerous for exact counting, and fast growers like *Trichoderma viride* very quickly overgrew the whole plate. The number of colonies per plate was in the region of 200. A similar behaviour was noted in the plates prepared from the 2·5 cm. samples of the A peat.

Colonies of the same species developed earlier on the plates inoculated from the surface samples than on those from the deeper samples. This seems to suggest that the fungi are in a more active state in the surface peat than in the deeper layers.

The behaviour of the microfloral composition with variation in depth differed considerably in the two peats, and is treated separately.

PEAT A. Fungi were found to be present at all levels in this peat, but their abundance decreased with depth. Fig. 3 shows the variation in the number of

colonies which developed on plates prepared from samples taken from different levels of A_2 and A_3. The number of colonies drops rapidly from 0 to 10 cm. In the 20–25 cm. level of A_3 the number of colonies increases markedly, and this increase is caused largely by the abundance of a single species, M 10. (In the 25–30 cm. level of A_1, this pronounced rise, caused by the abundance of M 10, was also noted). The dotted line in Fig. 3 shows the variation in the numbers of all colonies in A_3 exclusive of M 10. In A_2, where the increase in the number of colonies in the 20 cm. region was not very marked, M 10 was not present in large numbers (cf. Fig. 1 f.). The fact that the A_2 site was situated at a higher level than either A_1 or A_3, nearer the wet bog above and on less pronounced slope, might be suggested as a possible explanation of this difference.

Although the number of fungal colonies developing on the plates decreased with depth, the number of species recorded for each level below the surface layers remained very constant, 6 or 7 for each level, as is shown in Fig. 1 a. This is very different from the behaviour of the fungal flora of grassland soil as reported by Warcup (1951). He found that, with increase in depth, there was a large falling off in the number of species as well as in the number of colonies developing on the plates. In the surface layers, 8 or 9 species have been recorded per sample. Far more were certainly present but overgrown by the more vigorous and antagonistic Penicillia and *Trichoderma viride.*

A list of the fungi isolated has already been given. The distribution of the more commonly occurring species is shown in Table 2 and in Fig. 1. In the upper 7·5 or 10 cm., species of *Penicillium*, especially *P. lividum*, *P. melinii*, *P. thomii* and *P. spinulosum*, were dominant and formed about 90% of the colonies on the plates (Fig. 1, b). *P. lividum* appeared to be definitely dominant at the surface. Its frequency decreased rapidly with depth, and it usually faded out at 7·5 cm. (Fig. 1, c). *P. melinii* was dominant in the subsurface layer, being most common at 2·5 and 5 cm. and it remained frequent down to 10 cm. (Fig. 1, d). *P spinulosum* and *P thomii* were met with regularly, but not in large numbers. *Trichoderma viride* was also regularly recorded from the surface samples (Fig 1, g). Since this species and the Penicillia have very pronounced antagonistic properties, the recording of other species was rendered very difficult. However, the following observations were possible :— *Mucor ramannianus* was frequent at the surface and persisted down to 10 cm , though in greatly reduced numbers ; M 8, an Ascomycete, was present in the 2·5 and 5 cm level of all three sampling sites, and was exclusively confined to this level ; *Mortierella* sp (M 1), was frequent in the upper 10 cm., and occurred also in the lower layers ; *Mortierella* sp (M 9) was recorded as frequent from the 0 and 5 cm samples of A_3 only.

A definite change in the species association was observed below 10 cm. Here M 10 was the dominant fungus appearing on the soil plates, especially those from A_1 and A_3 (Fig. 1, f). In A_2, though present and well distributed throughout the lower layers, it was not at all so dominant, nor did any other fungus appear to replace it on the plates. Below 10 cm. the number of Penicillia colonies dropped rapidly.

Fig. 1, b shows the distribution of Penicillia throughout A_2 and A_3. In the lower layers, Penicillia sometimes occurred as single colonies on only one of the plates prepared from the peat of a given depth. This, along with the fact that they developed so quickly, suggests that they may, in some cases, have been air-borne spores from the surface which contaminated the sample during collection. However, since the material for plating was taken carefully from the interior of the peat plugs, these odd colonies were certainly not all contaminants. *P. jenseni*, *P. stoloniferum*, *P. oxalicum*, as well as the species already mentioned, were sporadic and rare in these lower layers. Three other species occurred constantly in the deeper layers, *Verticillium* sp. M 14, M 19, and *Trichoderma viride*. Fig. 1, e and g show the distribution of *Verticillium* and *Trichoderma*. They decreased in abundance with depth, and, except for isolated colonies at 30 and 40 cm. in A_3, disappeared in the central region of the profiles, where M 10 was dominant. The distribution of M 19 was rather uniform.

PEAT B_2. Fig. 4 shows that the number of colonies developing on the plates prepared from samples from different levels decreases with depth. The fungi fade out at a depth of 25 cm., (except for an isolated colony on the 40 cm. plate). Fig. 2, b shows the distribution of all *Penicillium* spp. which were definitely dominant from 0 to 5 cm. *Trichoderma viride*, whose distribution is shown in Fig. 2, d, was also present in this region. Below 10 cm., the Penicillia were sporadic and rare. *P. lividum*, so common on the surface plates of the A peat, though present was rather infrequent. *P. melinii* occurred in every sample from 0 to 10 cm. One species of *Penicillium*, unrecorded for A, was very common in B_2,—*P. nigricans*, (0–5 cm.).

Below the region of *Penicillium* dominance, M 18 was frequent and evenly distributed; another sterile form M 17 was also common. Throughout the whole profile, *Mucor* sp. (M 16) was regularly present in every sample from 0 to 20 cm. Its distribution is shown in Fig. 2, c.

PEAT B_1. Although the fungus flora of B_1 resembled that of B_2 it differed in so many points that it would seem to be a separate type. The fungi disappeared between 15 and 20 cm. in the undisturbed bog, although the two plates prepared from the 20 cm. sample taken from beside a turf cutting produced 12 colonies. The incipient effects of drainage beside the turf cutting was probably responsible for the difference. The following species, common and characteristic in B_2 were completely unrecorded in B_1 :— *Mucor* sp. (M 16), *Penicillium melinii*, *P. nigricans*. The strain of *Trichoderma viride* present in B_1 seemed to be far more virulent and fast-growing than that of B_2. Further differences may be seen in Table 2.

It may be interesting to note by way of comparison, that in an isolated sample taken from 15 cm. under a water-logged *Sphagnum cuspidatum* hollow in a raised bog near Newbridge, M 17 was very common, and *Penicillium spinulosum* and *P. paxilli* were present. M 18 did not appear.

NOTE ON BACTERIA. No detailed investigation of the bacterial population of the peats was undertaken, nor was any attempt made to identify the bacteria isolated.

Bacteria were recorded in all samples from the A_2 peat. The maximum bacterial population seemed to be in the 30–40 cm. region; the lower horizons (60 and 70 cm.) were relatively poor in bacteria. Bacteria were recorded at all levels from 0–50 cm. in B_2. The 60, 70, and 80 cm. samples produced no colonies. No attempt was made to isolate anaerobes.

Correlation of the Distribution of the Microflora with the Physical Properties of the Peat.

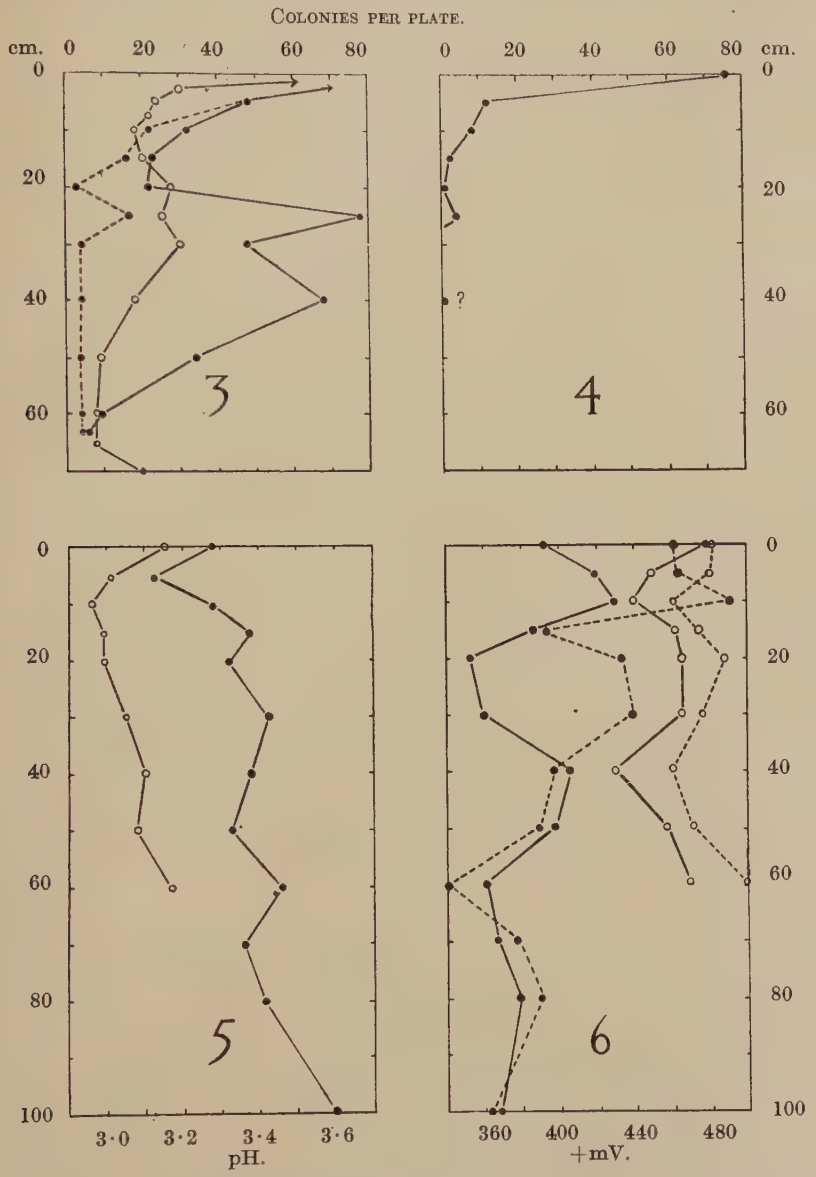
Since it was not possible to determine the physical properties of each sample investigated, a series of fresh samples was collected from points near A_1 and B_2 on 28/5/'52, following three weeks of drought. Table 3 shows the results of the following determinations :— Ash and water content, temperature, pH, and electric potential of the peat.

Table 3. Physical properties of peats A_1 and B_2.
(Ash and water as % of dry weight; E_5 (1), initial value, E_5 (2) 'steady' value of E_5).

	Depth	Ash	Water	°C.	pH	E_5 (1)	E_5 (2)
A_1	0 cm. ...	—	—	10·0	3·15	480 mv.	482 mv.
	5 ,, ...	—	—	10·0	3·01	445 ,,	480 ,,
	10 ,, ...	—	—	10·0	2·96	440 ,,	462 ,,
	15 ,, ...	2·7%	388%	—	2·99	462 ,,	474 ,,
	20 ,, ...	—	—	10·1	2·99	465 ,,	488 ,,
	30 ,, ...	—	—	9·7	3·05	465 ,,	476 ,,
	40 ,, ...	—	—	9·1	3·10	430 ,,	460 ,,
	50 ,, ...	3·9%	361%	8·5	3·08	457 ,,	471 ,,
	60 ,, ...	—	—	7·8	3·17	469 ,,	489 ,,
B_2	0 ,, ...	—	—	11·0	3·28	392 mv.	461 mv.
	5 ,, ...	—	—	—	3·12	419 ,,	463 ,,
	10 ,, ...	—	—	11·2	3·28	430 ,,	491 ,,
	15 ,, ...	1·8%	1,120%	—	3·37	387 ,,	393 ,,
	20 ,, ...	—	—	11·4	3·32	353 ,,	433 ,,
	30 ,, ...	—	—	11·0	3·43	361 ,,	439 ,,
	40 ,, ...	—	—	10·3	3·38	406 ,,	398 ,,
	50 ,, ...	1·2%	1,011%	9·8	3·33	398 ,,	390 ,,
	60 ,, ...	—	—	9·5	3·46	361 ,,	339 ,,
	70 ,, ...	—	—	9·1	3·36	367 ,,	377 ,,
	80 ,, ...	—	—	8·5	3·42	379 ,,	390 ,,
	100 ,, ...	1·5%	762%	—	3·60	369 ,,	363 ,,

ASH AND WATER CONTENT. In B the water content was remarkably high, although the samples were taken at the end of a three weeks' drought, and much of the surface Sphagna had dried out. In the surface layers, (0–50 cm.), it was well

above 90% fresh weight; in the lower layers it dropped somewhat, to 88%. In A the water content was considerably lower, 79% of fresh weight. The figures reckoned as % of dry weight give a better idea of the very large difference between



FIGS. 3—6. 3. Average number of fungus colonies recorded per plate at various depths in A_2 o——o and A_3 ●——● (●····● exclusive of M10.)

4. Do. B_2.

5. Variation of pH with depth in A_1 o and in B_2 ●.

6. Variation of redox potential (E_5) with depth in A_1 o and in B_2 ● ; initial value —— ; steady value.....

the two peats, —350% as against 1,000%. The B peat was therefore almost completely saturated with water, and had the consistency of butter at summer temperatures, while the A peat was of a more open, spongy texture, and far from saturation. (Samples were dried to constant weight at 120° C.).

The ash content of A averaged 3% of dry weight, that of B 1·5%, the latter figure being remarkably low, even for *Hochmoor*.

TEMPERATURE. As shown in Table 3, the temperature varied very little with depth in either peat. The difference between the upper and lower samples, (2·5° C.) would seem to be too small to have any significant modifying effect on the fungus flora.

PH VALUE. The pH value was measured with a glass electrode in the laboratory 24 hours after collection and without further moistening. In Fig. 5 are given the curves of pH *v.* depth for both peats. The pH of both peats was low, lying between 3·0 and 3·5 in most of the samples. Following a noticeable drop in the immediate sub-surface layer, there was a gradual increase with depth. Where measurements were made right down to the bottom of the B peat, (as in B_1), this rise was found to continue, and in the lowest sample, where the peat was mixed with granite detritus, it reached the value of 3·75. No exact correlation of floral change with pH was evident.

OXIDATION-REDUCTION POTENTIAL. The oxidation-reduction potential of the samples was measured in the laboratory 24 hours after collection with a Beckman pH meter, (platinum and calomel electrodes). The samples were collected in corked glass specimen tubes (1 inch bore) and were not further moistened. The peat was exposed to the air only in the short interval of transferring the peat to the container of the meter. Electrodes were inserted 1 cm. into the peat. With most of the samples, a rapid drift in the reading was observed immediately after immersing the electrodes, but the value gradually became relatively steady after 2 to 10 minutes. The initial and ' steady ' values, (E_5 (1) and E_5 (2)) of the A and B samples are given in Table 3 and plotted in Fig. 6. Since the oxidation-reduction potential varies with pH, the readings (Eh) are corrected to pH 5 (E_5) on the basis that one unit increase in pH is equivalent to 58 mv. decrease in E_h. Results are expressed with reference to the calomel electrode.

Pearsall (1938), by correlating the nitrate content and the ratio of ferrous to ferric iron in a number of soils and peats with their redox potential, came to the conclusion that a redox potential of + 350 mv could be taken as an arbitrary level above which soils and peats could be considered to be predominantly oxidising. Fig. 6 shows that the E_5 value for A lay well above 350 mv. In B, the E_5 value fluctuates greatly, but is nearer to this value ; the general trend is towards a decrease with depth, but in one sample only (60 cm.) was E_5 below 350 mv. Errors of determination are probably responsible for much of this fluctuation.

Certain tentative correlations between the curves and the vertical distribution of the microflora and the roots of vascular plants may be pointed out. In the curve for A, two minima are quite distinct, one at 10 cm., the other at 40 cm. That at

10 cm. corresponds with the change over from dominance by the Penicillia to dominance by M 10 in A_1 and A_3. The other minimum occurs in the region of a discontinuity in the peat, where there was no noticeable change in the constitution of the microflora, but where the fine roots of *Calluna* began to be abundant.

In the upper 40 cm. of B, the curves for the initial and steady values do not follow one another very exactly, as they do in A, but below this level they are more or less parallel. There is a definite minimum in the region of 60 cm. the level at which bacteria seem to fade out, and beyond which the live roots of *Eriophorum angustifolium* and *Trichophorum* (*Scirpus*) *caespitosum* do not penetrate. Below this level, the curves are far more regular, perhaps because of the absence of roots or micro-organisms actively secreting oxidation-reduction compounds.

It is obvious that many more measurements would be needed before any definite conclusion could be drawn. Yet, even these limited data show the possibility of there being a correlation between the redox potential and the vertical distribution of the microflora and the roots of vascular plants. They at least serve to indicate an inviting field of research.

Discussion.

Warcup (1951) considers that the two chief factors influencing the composition of the fungal flora of grassland soils are pH and abundance of humus,—pH governing the specific composition, amount of humus influencing both the species present and their abundance. He considers low humus content to be the limiting factor for most fungi. Grey and McMaster (1933) likewise found that in Canadian virgin podsols, biological activity was almost entirely confined to the mat of organic matter covering the mineral soil; activity in the mineral layers was less than 4% of the surface activity. In peat, however, both these factors, pH and humus, remain relatively constant. Other factors must then be sought in order to account for the decreasing number of colonies developing on the plates prepared from progressively deeper samples, especially in the B peat, as also for the notable difference between the specific composition of the microflora of the surface layers and that of the lower layers. It seems reasonable to suggest that aeration may be the major factor in question in peats which are more or less waterlogged. Even in mineral soils aeration would seem to influence the microflora, as the results of Bisby *et al.* (1935) would indicate. They found that, in the surface layer of Canadian virgin podsols, facultative anaerobic fungi formed less than 1% of the total fungi isolated; in the lower layers their abundance increased considerably and formed up to 50% of the total fungi isolated. The correlations noted above between the redox potential of the peat and the distribution of the microflora would also seem to suggest that the oxidising power of the peat is a factor governing the distribution of the peat microflora.

The small amount of work published on the fungal flora of peat does not permit any generalisations about its ecology to be made. The present investigation reveals that the dominant fungi, especially in the surface layers, were the Penicillia. In the B peat they formed 35% of the fungi isolated, in the A peat 27%. Warcup

(1951) found that they were characteristic of podsol grassland, and formed 23% of the total species isolated, while in basic grassland of pH 7·6 and 7·8 they formed but 13% and 8% of all the species isolated. Bisby *et al.* (1935) likewise reported that they formed a large proportion of the species isolated from Canadian podsols and peat. It seems therefore that the dominance of Penicillia is more pronounced in saturated peats than in spongy or heath peats; more pronounced in peats than in acid podsol; more pronounced in acid than in alkaline soils.

The results of Boswell and Sheldon (1951), who investigated the microflora of the upper 5 cm. of *Eriophorum* peat, are in marked contrast to those of the present study. *Eriophorum* peat from the Dublin mountains, though similar to *Scirpus* peat, differs in some of its physical properties. The dominant fungi recorded by Boswell and Sheldon, *Cephalosporium* spp., were apparently absent from the peats of the present study, while *Penicillium* spp., dominant in B_2, were recorded but occasionally by Boswell and Sheldon. Besides, the number of colonies of *Cephalosporium* per gram of peat recorded by them is far in excess of the total number of fungus colonies of all species recorded per gram of the surface layers of either of the peats examined in the present study, 10^9 to $4{\cdot}3 \times 10^{10}$, as compared with 10^4, approximately. This difference in results obtained is probably due both to the different techniques used and to a real difference between the microflora of the two peats. Boswell and Sheldon used the dilution method and discarded the washings which did not form a suspension or go into solution. It seems legitimate to conjecture that in the dilution method, the colonies isolated originated almost entirely from wetable spores, the mycelium being rejected with the peat residue not forming a suspension. In Warcup's soil-plate method, however, actively growing mycelium would be given an initial advantage. The fungi recorded by Boswell and Sheldon are all heavy sporers. In the present study, of the 60 species isolated 20 were sterile mycelia, at least two of which (M 18, M 19) were relatively abundant in various samples. Of the sporing colonies, the majority probably originated also from actively growing mycelium, for, as reported above, in all cases except one the young colonies developed out of humus particles, not from naked spores. This, along with the rapidity with which the colonies developed from the surface samples, would suggest that they originated from actively growing mycelium. It is the presence and relative abundance of such actively growing fungi that it is desirable to record from an ecological point of view; and as Garrett (1951) has pointed out, Warcup's soil-plate method seems to be the most satisfactory non-selective method for recording such fungi.

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Summary.

(1) The microfungal flora of two peats from the Dublin/Wicklow Mountains has been studied; one of these is a spongy peat covering a steep slope and bearing

a dense growth of *Calluna* (A); the other is a typical *Scirpus* bog (B). Special attention was paid to the variation of this flora with depth.

(2) 61 species of fungi have been isolated by the soil-plate method; 49 from A, 23 from B. *Penicillium* was by far the most common genus isolated; species of *Mucor, Mortierella* and *Trichoderma* were also common.

(3) In A, fungi and bacteria were recorded from all levels; the upper 10 cm. was dominated by Penicillia, lower levels by an unidentified species, M 10.

(4) In B, fungi disappeared below 25 cm., the numbers falling off with depth. Penicillia dominated at all levels, but not so noticeably as in A. Bacteria were not recorded below 50 cm. The surface layers showed by far the greatest fungal activity in both peats.

(5) The distribution of the micro-organisms shows some correlation with changes in the redox potential of the peat with depth.

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